Assessment of Energy Demand Considering Different Model Simulations in a Low Energy Demand House

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Abstract—The lack of insulation along with the existence of air leakages constitute a meaningful impact on the energy performance of buildings. Both of them lead to increases in the energy demand through additional heating and/or cooling loads. Additionally, they cause thermal discomfort. In order to quantify these uncontrolled air currents, the Blower Door test can be used. It is a standardized procedure that determines the airtightness of a space by characterizing the rate of air leakages through the envelope surface. In this sense, the low-energy buildings complying with the Passive House design criteria are required to achieve high levels of airtightness. Due to the invisible nature of air leakages, additional tools are often considered to identify where the infiltrations take place such as the infrared thermography. The aim of this study is to assess the airtightness of a typical Mediterranean dwelling house, refurbished under the Passive House standard, using the Blower Door test. Moreover, the building energy performance modelling tools TRNSYS (TRaNsient System Simulation program) and TRNFlow (TRaNsient Flow) have been used to estimate the energy demand in different scenarios. In this sense, a sequential implementation of three different energy improvement measures (insulation thickness, glazing type and infiltrations) have been analyzed.

Keywords—Airtightness, blower door, TRNSYS, infrared thermography, energy demand.

I. Introduction

THE global warming along with the increase of energy consumption and CO_2 emissions are major concerns in today's society [1]. Moreover, the progressive increase in temperatures resulting from the climate change is leading to greater building cooling demands, especially in the southern Europe [2], [3]. Indeed, buildings are responsible for about a third of global energy consumption and a quarter of CO_2 emissions [4]. In Spain, housing accounts for 17% of total energy consumption, which is largely due to the constructive features of the current building park [5]. Many of the residential buildings were built in accordance with very low or even no energy demand limitation requirements. Predictions state that the energy demand in the building sector will continue to grow in the next decades [6]. And this, linked to the increase on the cost of energy sources, should trigger a change in the forthcoming building projects or interventions. For this reason, upgrading the building park in order to achieve more efficient dwellings and acting on the energy demand is a matter of paramount concern.

Governmental policies such as the Energy Performance of Building Directive (2018/844) aims to promote the improvement of the energy performance of buildings within the European Union though the use implementation of advanced construction and insulation materials [7]. Some studies carried out on building interventions analyze passive measures to counteract the buildings consumption. Among them, increasing thermal insulation and reducing the infiltrations will have a greater effect on global energy demand [8]. Barea et al. also state that good natural ventilation performance is essential to achieve savings of up to 72% of the energy required for cooling [9].

Since buildings' airtightness may have a significant impact on the energy demand, its estimation is advisable. To do so, the Blower Door test, which is a standardized procedure (ISO 9972:2015), can be performed in order to analyze the rate of air leakages through the envelope surface [10]. Air leaks represent measures of infiltrations at 50 Pa pressure difference between the outside and the inside. When the Passivhaus Standard is considered, a Blower Door Test result to 50 Pa of 0.6 renovations per hour is limited. Additionally, with the aim of determining where the air leakages take place, the infrared thermography (IRT) can be used [11]. IRT is a non-destructive technique that captures the infrared radiation emitted by the surfaces. Although air is transparent in the infrared radiation spectrum, it can be identified when a thermal contrast between the interior and exterior of the building is generated. Hence, the surfaces exposed by the incoming air from the outside show different temperatures, which makes it possible to know where the infiltrations occur [12].

On the other hand, the implementation of energy simulation tools in the building design steps or in the estimation of the building thermal behavior is becoming quite common [13]. These building performance simulation tools, such as TRNSYS, are performed to simulate heating and cooling demands and they allow us to estimate future energy needs in buildings in a wide range of different scenarios [14].

The main objective of this work is to estimate the heating and cooling demand for a low energy demand house located in the Mediterranean area. Starting from an initial model, three mitigation measures have been implemented and simulated in TRNSYS in order to evaluate the new energy performance.

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Moreover, a Blower Door Test along with IRT inspection was carried out in order to estimate and locate air leakages.

II. Materials and Methods

A. Building Description

A residential house consisting of two floors with a total surface area of 101.8 m^2 and a flat roof area of 16.6 m^2 has been evaluated. It presents a square plan on the ground floor and a rectangular one on first floor and its alignment is north-south. The house is located on the east coast of Spain, and it has 4 façades with 8 openings (windows and doors).

B. Weather Data

The weather data files used were obtained from the Meteonorm® Database exported into TM2 format. These weather files correspond to specific locations and contain parameters from average climate readings such as dry bulb temperature, wind velocity and direction, relative humidity, or global horizontal solar radiation. Specifically in this work, the weather data file from Valencia was used.

C. Blower Door Test and Leakage Detection with IRT

Blower Door Tests according to EN 13829 and ISO 9972:2015 were performed on different occasions: prior being restored and after the constructive improvements were carried out. The number of renovations per hour obtained in the Blower Door Test result at 50 Pa were 7.7 and 3.2 respectively. On the other hand, IRT was used in order to detect the air leakages. A FLIR T1020 thermal camera (FLIR Systems, Inc., Wilsonville, OR) with a pixel resolution of 1020x, and thermal resolution of 20 mK was used.

D. Software Simulation Tools

The transient simulation software TRNSYS-18 was used to evaluate the energy demand of the house in the different scenarios. Moreover, TRNFlow (TRaNsient Flow), a tool on TRNSYS, was used to introduce ventilation and infiltration values.

E. Energy House Models

In this work, 3 different models linked to different mitigation measures have been considered (Table I). All of them were obtained from variations carried out on the initial model (Model 0). First, the 3D model of the house was created with Google SketchUp, which generates an *idf* file with multizone areas and geometric information. Then, the *idf* file was imported to TRNSYS, which creates a Type-56, where all the information of the building (envelope, heating, and cooling systems, etc.) is included.

The initial model (Model 0) was developed in compliance with the Spanish constructive standards [15] and it did not consider any limitation on the infiltrations (through the renovations per hour). In fact, in this initial model, along with models 1 and 2, the number of renovations per hour was established at 7.7, value obtained in the Blower Door test. Then, in each of the following models, different mitigation measures were considered in order to evaluate the effects on the energy demand.

TABLE I
House Models and Their Main Characteristics

Model	Characteristics	Renovations per hour
Model 0	Initial model	
Model 1	Model 0 + enclosure insulation	7.7
Model 2	Model 1 + change window type	
Model 3	Model 2 + reducing infiltrations	0.6

Note: 50Pa air changes

In Model 1 the enclosure insulation thickness was increased, and thereby, the U-values as shown in Table II.

TABLE II
Enclosure U-Value (W/m^2 K) and Thickness

Climatic area		Thickness	U
Model 1	External wall	0.305	0.785
	External Floor	0.375	0.525
	External Roof	0.09	0.588
Model 2-4	External wall	0.435	0.221
	External Floor	0.515	0.185
	External Roof	0.23	0.192

Model 2 also adds glazing modification using a low emissivity 4/8/4 with a U-value of 2.48 W/m^2K glass, whereas the initial model had clear glass 4/6/4 with a U-value of 3.44 W/m^2K. Finally, the maximum reduction of infiltrations has been carried out in Model 3. In this sense, a nearly-0 building is to be achieved through the surface openings to the exterior to 0.6 renovations per hour. Air leaks were calculated with TRNSFlow. To consider the envelope airtightness, leakage openings were defined on the walls. In the model the equivalent large opening by an equivalent flow through a flat plate orifice has been calculated.

III. Results and Discussion

A. Effects on Annual Energy Demand

Fig. 1 shows the annual heating and cooling demand obtained in the baseline model (model 0) and the subsequent models where the improvement measures were implemented (models 1-3).

According to the results, the initial model (Model 0) presents the highest heating demand, specifically 93.34 W/m^2 per year. It should be taken into account that in this model, neither the insulation nor the reduction of infiltration was considered. That is, it was developed in compliance with the Spanish constructive standards and establishing the number of renovations per hour at 7.7. However, when the enclosure insulation increase was considered in Model 1, resulting in a heating demand reduction of 33% compared to the initial model. Regarding the cooling demand, little reduction is achieved, specifically 10% in Model 1 compared to Model 0. In model 2, in turn, the results obtained do not vary much with respect to the previous model (Model 1), since the change of windows type does not imply significant reductions in either heating or cooling demand. In Model 3, an infiltration level of 0.6 renovations per hour at 50 Pa was established using the standard PassivHaus resulting in a heating demand reduction of 83% compared to the previous model. However, in this scenario, the cooling demand increases, specifically by 1.5 and 1.4 in comparison with Model 0 and Model 2 respectively.

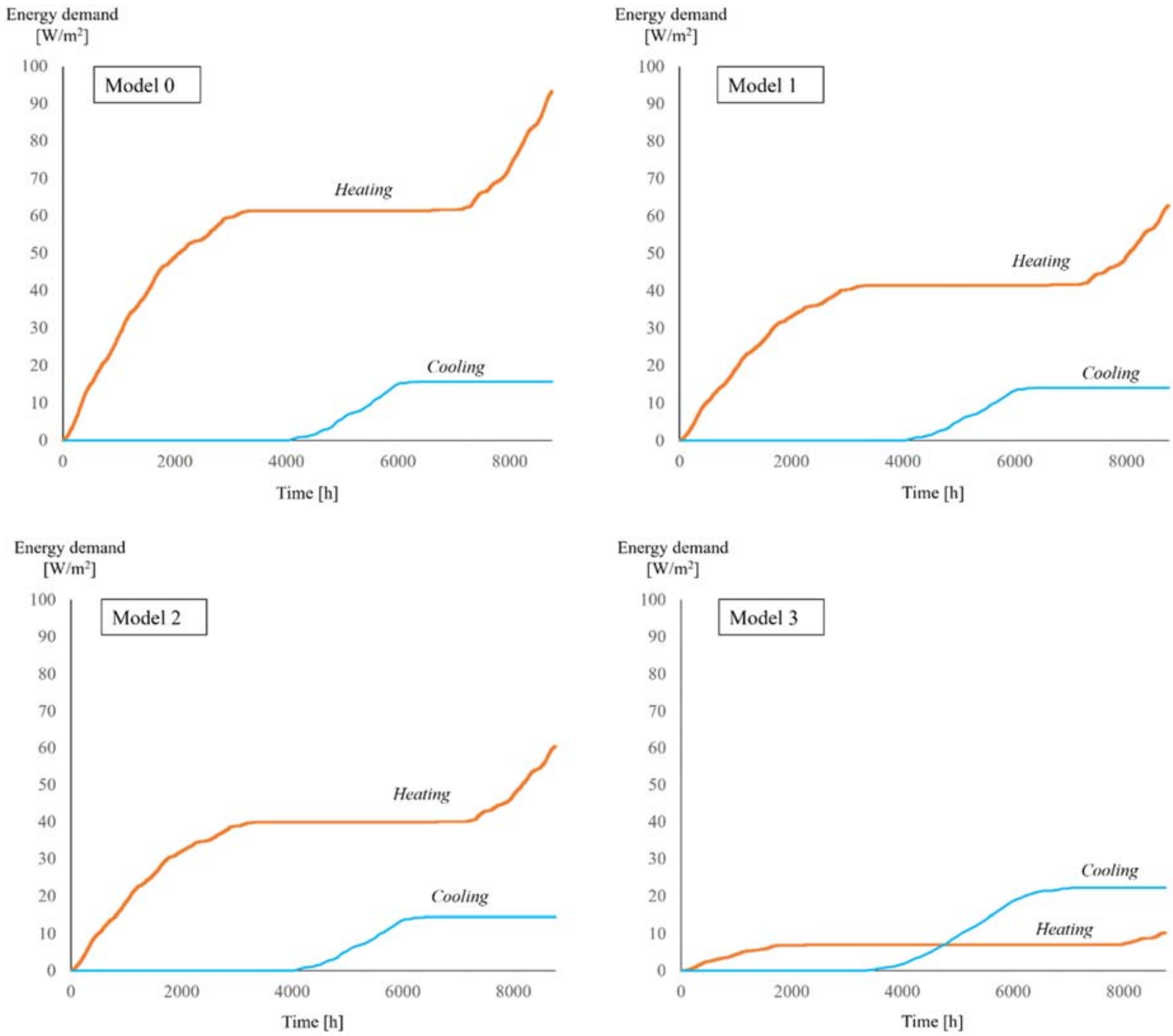

Fig. 1 Heating and cooling demands in one year for the different house models

Therefore, the decrease of average annual heating demand is significant when both envelope insulation increase and infiltration' reduction are considered. On the other hand, the cooling demand trend differs when the infiltration level is reduced. Overall, Model 3 comprises the scenario with the minimum energy demand over one year, achieving a reduction of 70% compared to the initial model.

In Spain, most of the state stock was built between 1960 and 2010, often resulting in building envelopes lacking the proper thermal insulation. In this sense, and according to the Eurostat dataset [16], to date, about 14% of European inhabitants live in a dwelling with leaking roofs, damp walls or rot in the window frames among others, which may constitute key drivers for buildings consumption. In the long term, climate change and the increase on average temperatures would have a direct effect on buildings energy consumption. Priority on high performance envelopes is advisable in colder areas, such as in Northern Europe in order to reduce the consumption per floor area [17]. Moreover, energy demand will shift towards cooling rather than heating [2]. In this sense, optimizing natural cross-ventilation during warm periods when the cooling demand prevails, results in energy savings [9].

B. Air Leakage Detection with IRT

In order to detect where the infiltrations took place, the Blower Door was established at 200 Pa between the exterior and the interior of the building. In these conditions, the IRT inspection was carried out throughout the house. It was performed in May, so that the air intakes are shown on the infrared images at higher temperatures. As can be seen in Fig. 2 (a), the airtightness of the windows was appropriate since no air infiltrations can be observed on the window frame. However, when the roof was inspected from the inside, leakages at different point were observed.

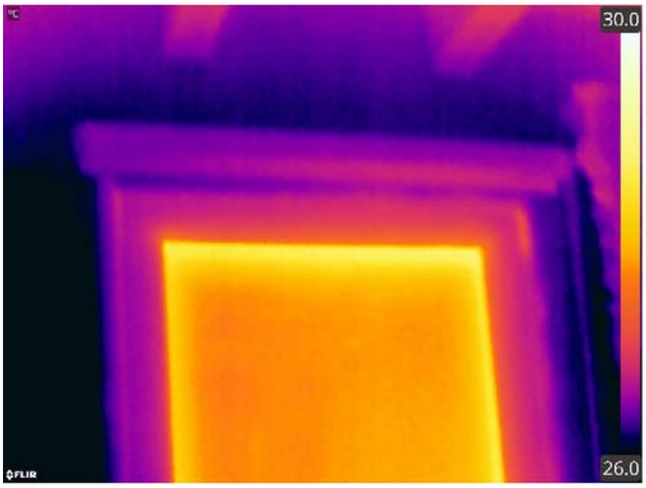

Fig. 2 (a) Window without air leakages

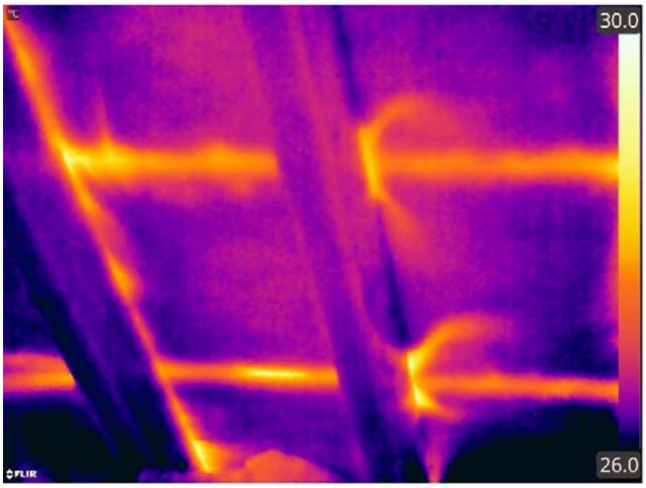

Fig. 2 (b) Air leakages on the roof

IV. Conclusions

The thermal behavior of a restored Mediterranean dwelling house has been analyzed considering different scenarios. Starting from an initial model in which no infiltrations reduction nor insulation improvements were considered, several mitigation measures were implemented through TRNSYS models. In this sense, the different models enable the performance' comparison in accordance with various scenarios. Thus, the initial model was optimized in order to obtain lower energy demand through different steps. Among them, increasing insulation (Model 1) and changing types of windows (Model 2) implied a reduction in the heating demand mainly. Finally, Model 3 pretended to achieve the minimum energy demand over one year. Additionally, a Blower Door Test was carried out and combining it with IRT, it was possible to detect where the air infiltrations took place.

Residential building should be redeveloped in order to achieve more efficient buildings. Achieving nearly zero demand houses will result in a reduction of energy demand, which is linted in a reduction of CO_2. On one hand, increasing the insulation and reducing the infiltrations is of paramount importance. On the other hand, to reduce the cooling demand, natural ventilation should be taken into account in hot periods.

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